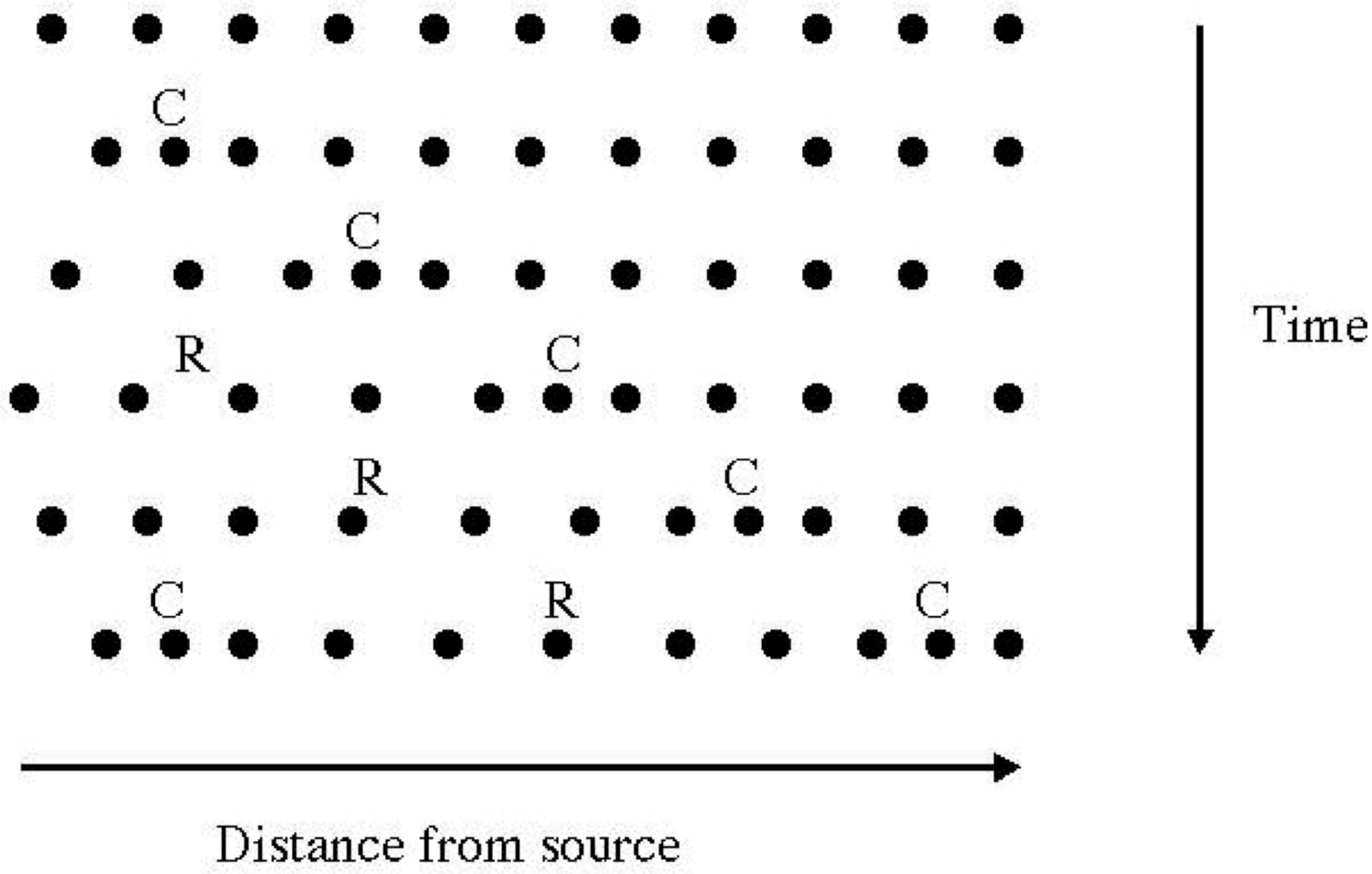
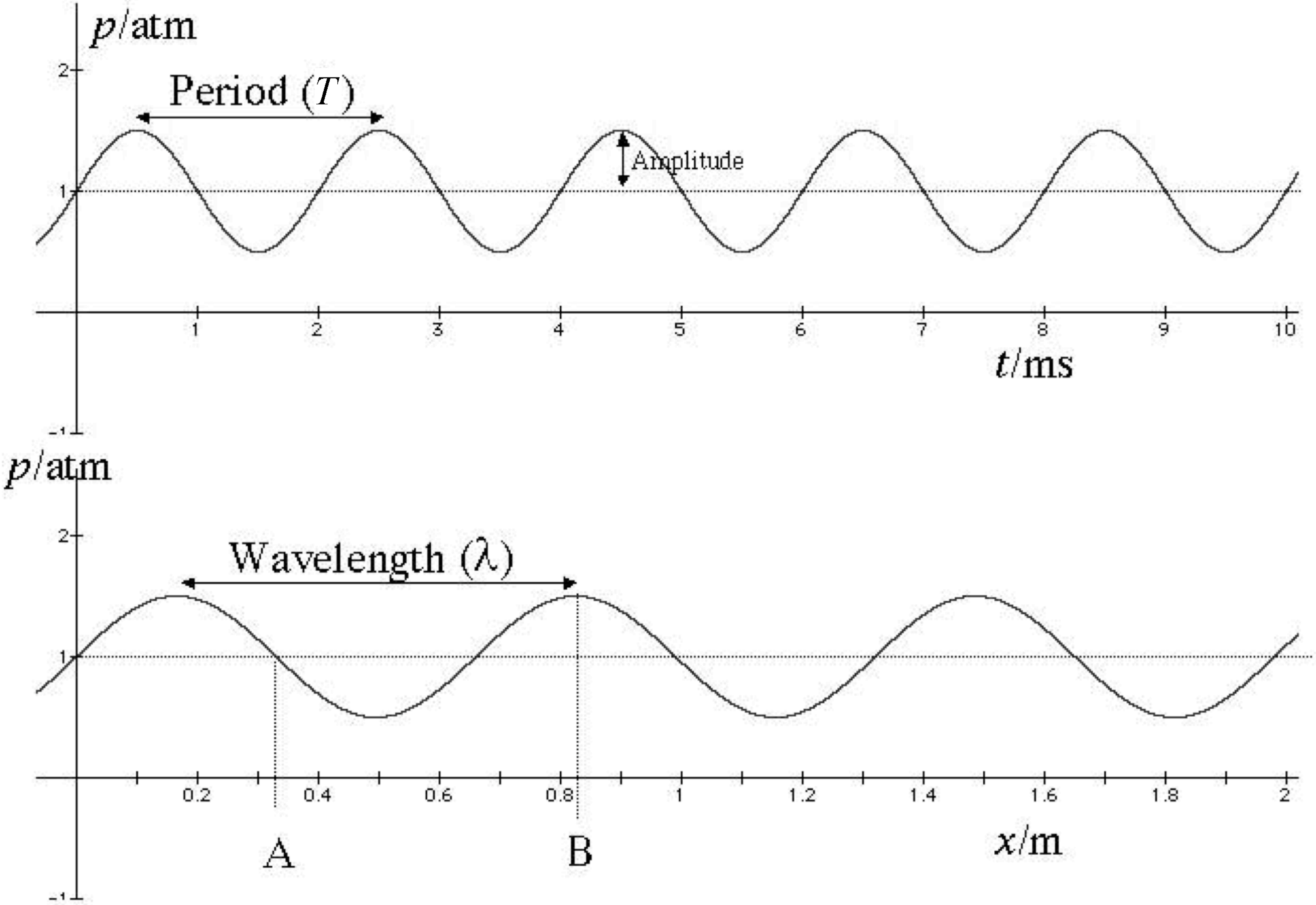
1. Physical properties of sound waves (Moore, 1989, pp. 1–3; Whelan and Hodgson, 1978, pp. 91–94,98,296–297)

- Sound waves can be either
  - *periodic*, e.g., tuning fork, violin; or
  - *non-periodic*, e.g., sonic boom, hand-clap.
- Sound waves can be either
  - *progressive*, e.g., tuning fork, violin; or
  - *stationary*, e.g., inside sounding organ pipe.
- The *source* of a sound wave is a vibrating object.
- The *disturbance* in a sound wave is a variation in pressure and density of the medium.
- Sound waves are *mechanical waves*—they can only be transmitted through a material medium (not a vacuum).

2. Oscillations of molecules in a sound wave



3. Waveforms and simple tones



4. Power, intensity, pitch and tones

- *Power* of a wave is amount of energy transmitted per unit time.

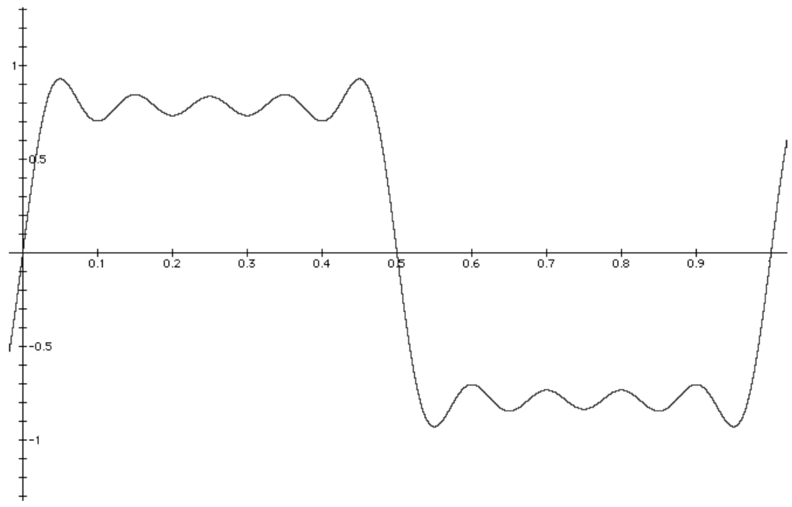
$$\text{Power} \propto (\text{frequency})^2 \times (\text{amplitude})^2 \times \text{speed}$$

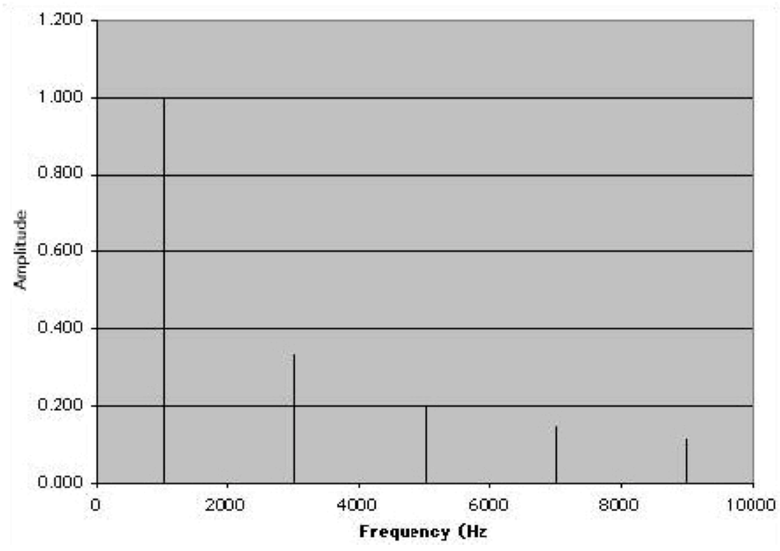
- *Intensity* is energy transmitted per unit time per unit area of the wavefront

$$\text{Intensity} = \frac{\text{Power}}{\text{Area of wavefront}}$$

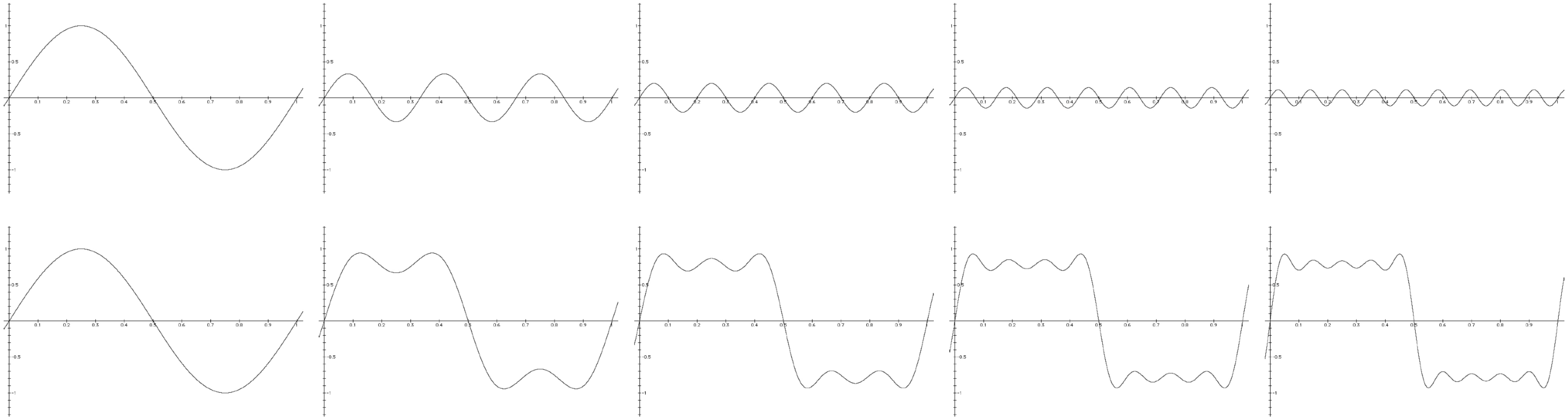
- *Loudness* depends on intensity and sensitivity of listener to frequency of the sound.
- Periodic sounds with a periodicity between 20Hz and 5000Hz evoke sensation of pitch.
- Pitch is that perceptual attribute of a sound in terms of which it may be ordered on a musical scale.
- A *tone* is a sound that has a pitch.

5. Fourier analysis and spectral representations (Moore, 1989, pp. 3–7)

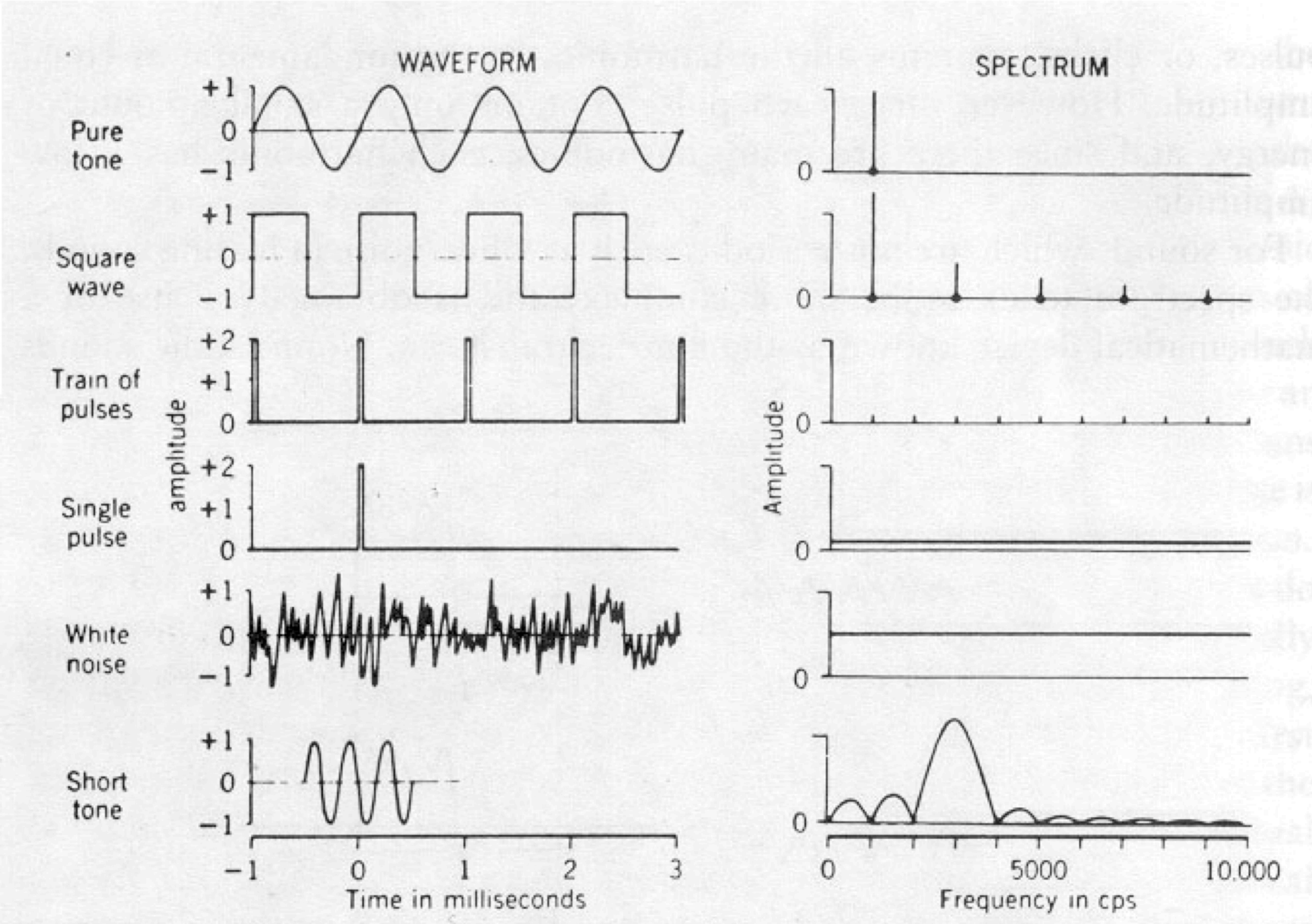




6. Constructing a harmonic complex tone



7. Examples of Fourier spectra



8. The measurement of sound level (Moore, 1989, pp. 7–10)

- Intensity is energy transmitted per second perpendicularly through 1m^2 of the wavefront. That is,

$$\text{Intensity} = \frac{\text{Power}}{\text{Area of wavefront}}.$$

- Auditory system can deal with huge range of intensity (e.g., gunshot is 10 000 000 000 000 times intensity of quietest detectable sound).
- We generally use a *logarithmic* scale for intensity.
- If we have two sounds with intensities I_1 and I_2 then the *sound level* of I_1 is

$$\log_{10}(I_1/I_2) \text{ Bels}$$

  greater than I_2.
- For example, if $I_1 = 100 I_2$ then

$$\log_{10}(I_1/I_2) = \log_{10}(100) = 2 \text{ Bels}.$$

- If we have two sounds with intensities I_1 and I_2 then the *sound level* of I_1 is

$$10 \log_{10}(I_1/I_2) \text{ decibels (dB)}$$

  greater than I_2.
- For example, if $I_1 = 100 I_2$ then

$$10 \log_{10}(I_1/I_2) = 10 \log_{10}(100) = 20 \text{ dB}.$$

- Increase in level of 10 dB corresponds to multiplying intensity by 10.
- Increase in level by 3 dB corresponds to doubling intensity.
- If $I_1 = I_2/10$ then

$$10 \log_{10}(I_1/I_2) = 10 \log_{10}(.1) = -10 \text{ dB}.$$

  That is, the sound level of I_1 is 10 dB less than that of I_2.

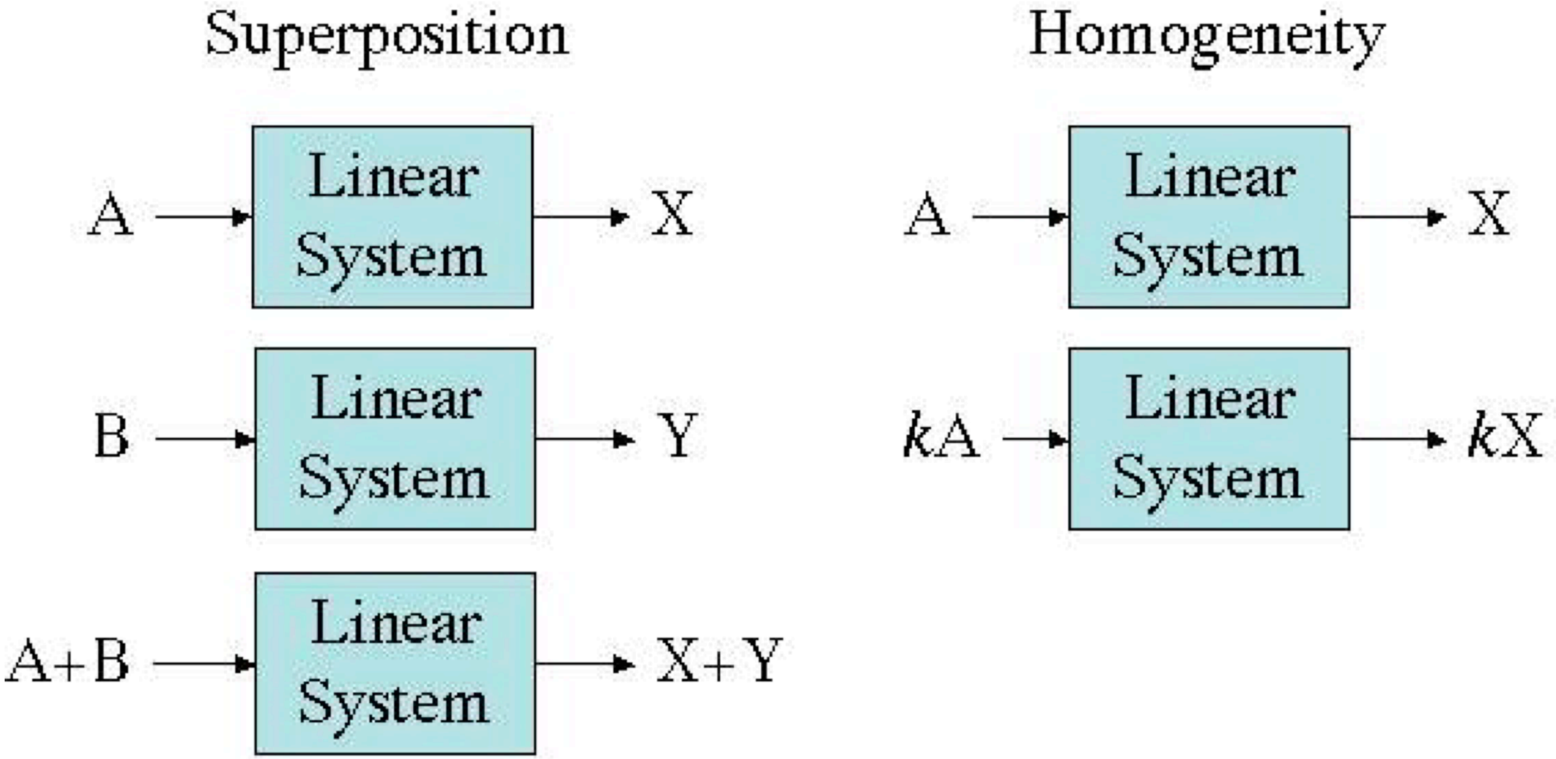
9. Sound pressure level and sensation level

- To express *absolute* sound levels, we need to define a standard reference intensity.
- Most commonly used standard reference intensity is 10^{-12} watts per square metre ($\mathrm{W/m^2}$) which corresponds to pressure variation of $2 \times 10^{-5}\mathrm{N/m^2}$ or 20 μPa (micropascal).
- The sound level of a sound relative to 10^{-12} watts per square metre is called the *sound pressure level* (SPL) of the sound.
- If SPL of a sound with intensity I is 60 dB SPL, then this tells us that

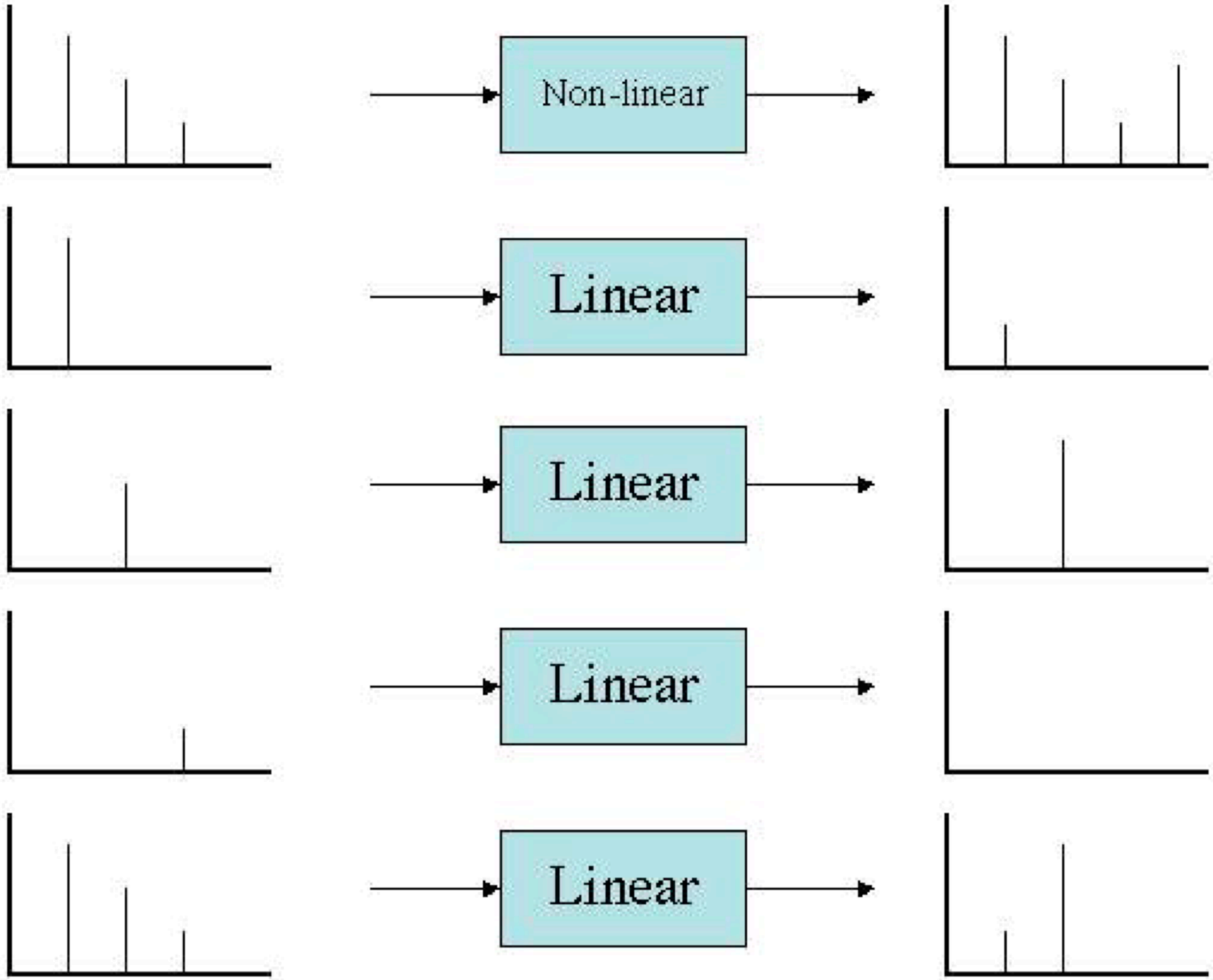
$$10 \log_{10}(I/(10^{-12})) = 60 \Rightarrow \log_{10}(I/(10^{-12})) = 6 \Rightarrow \frac{I}{10^{-12}} = 10^6 \Rightarrow I = 10^{-6}\mathrm{W/m^2}.$$

- O db SPL is close to human absolute threshold for 1000Hz tone (actually about 6.5 dB SPL on average).
- *Sensation level* of a sound is the intensity of the sound relative to the absolute threshold for that sound for a given individual, expressed in dB.

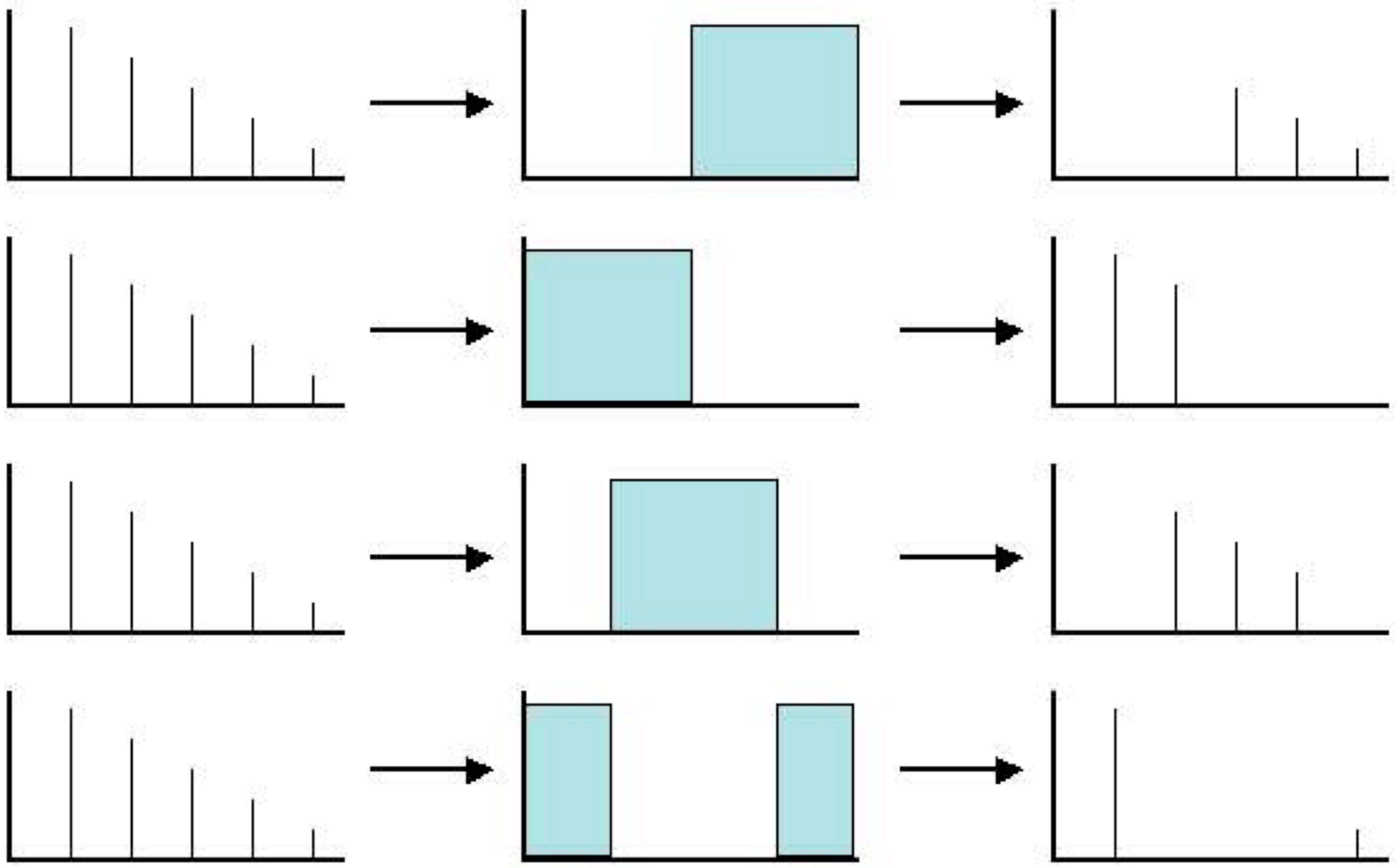
10. Linearity (Moore, 1989, pp. 10–11)



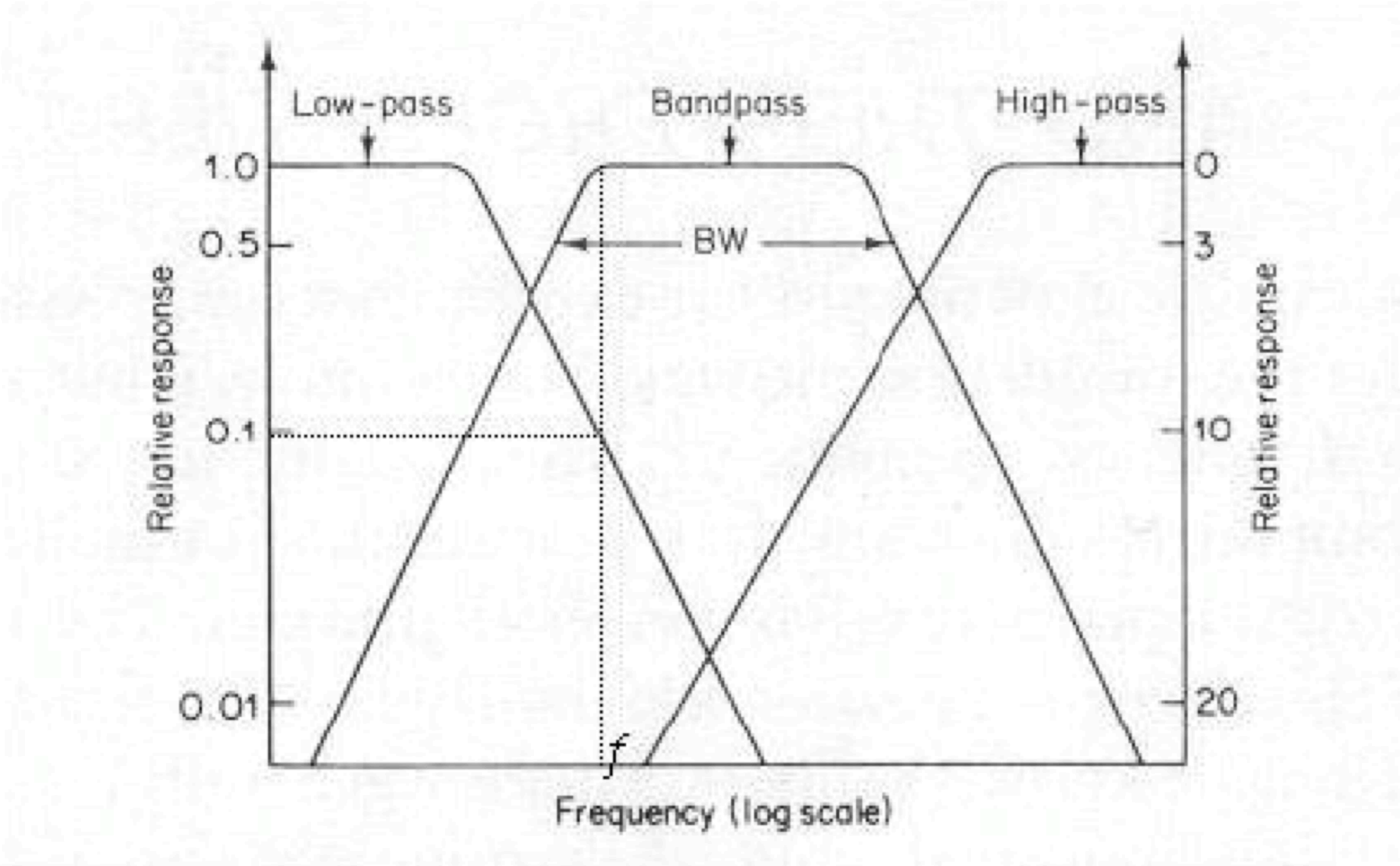
11. Linearity in acoustic systems



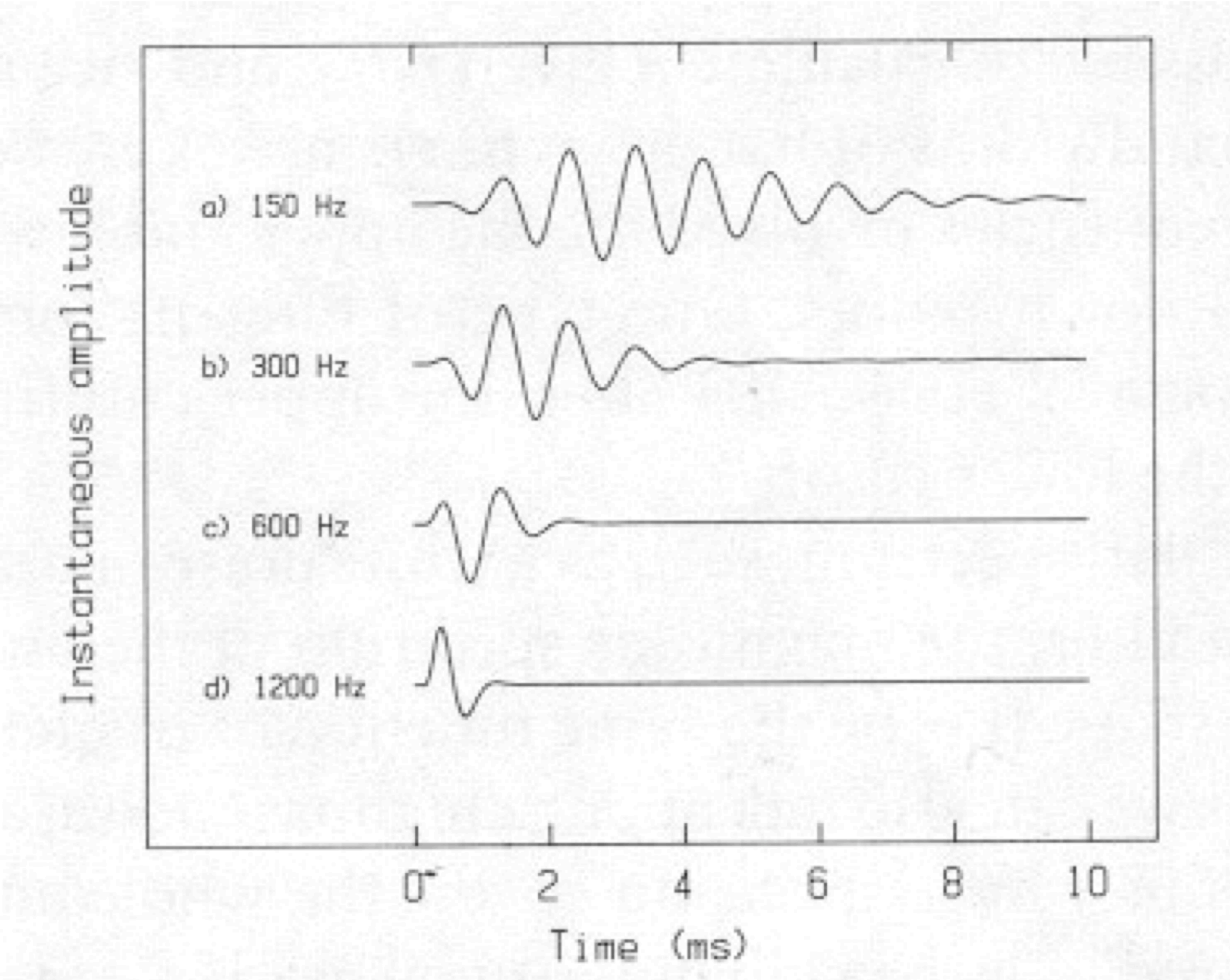
12. Filters and their properties (Moore, 1989, pp. 11–15; Roads, 1996, pp. 185–193)



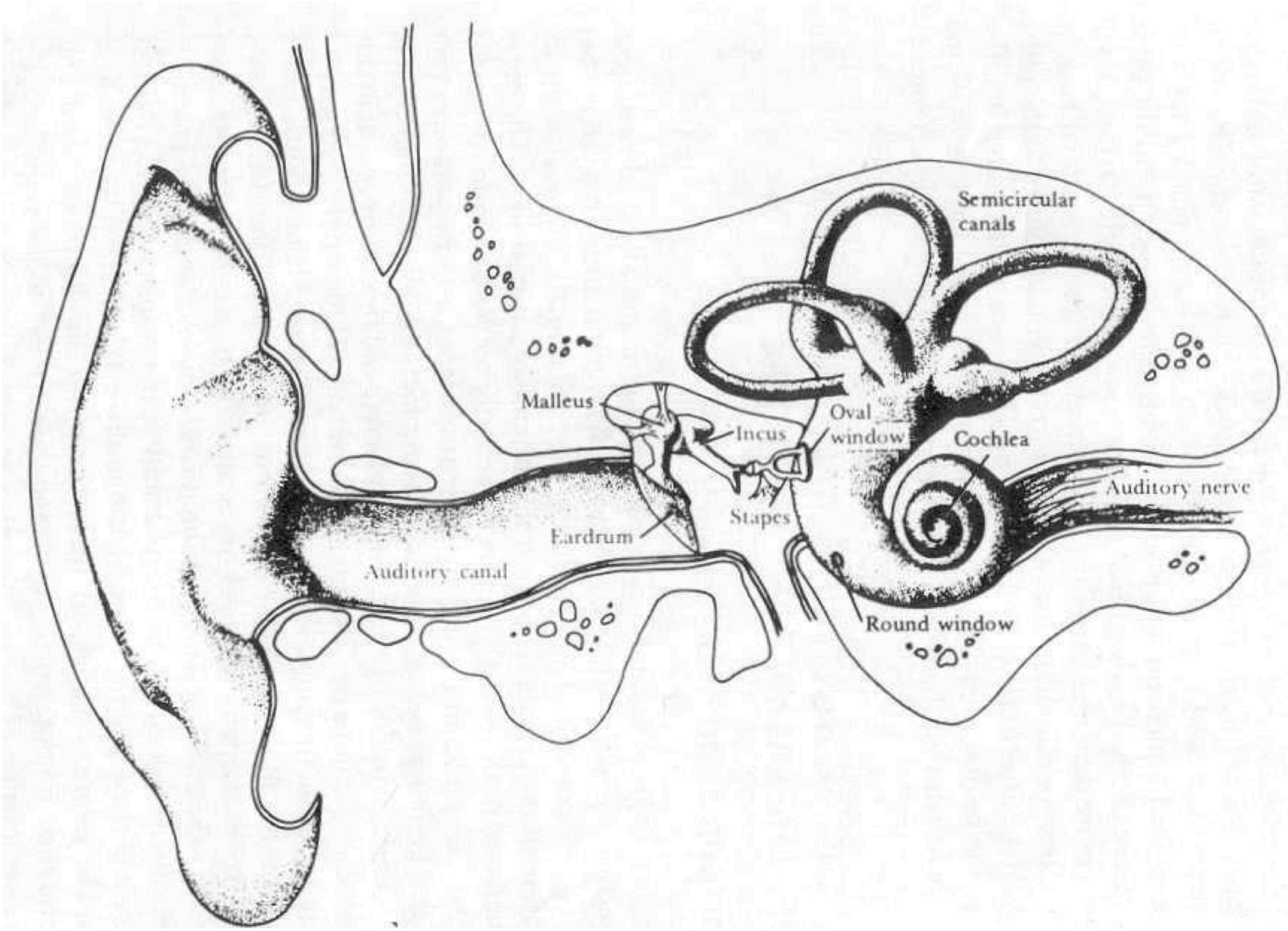
13. Real filters



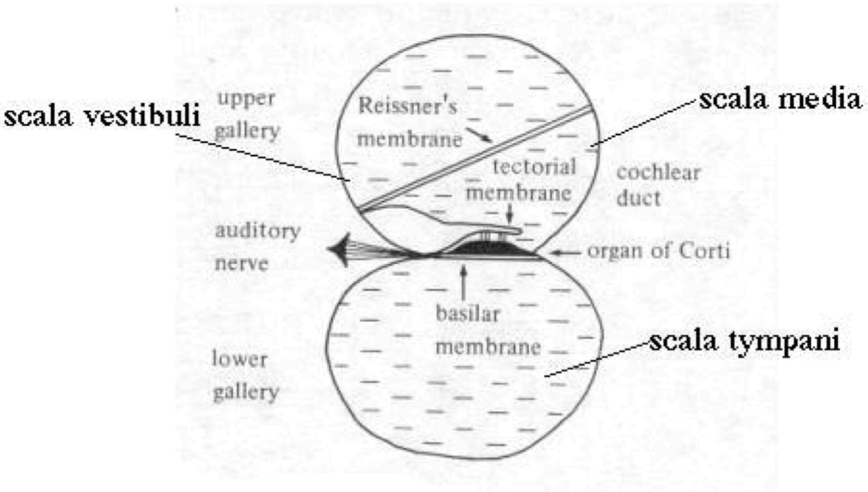
14. Impulse response

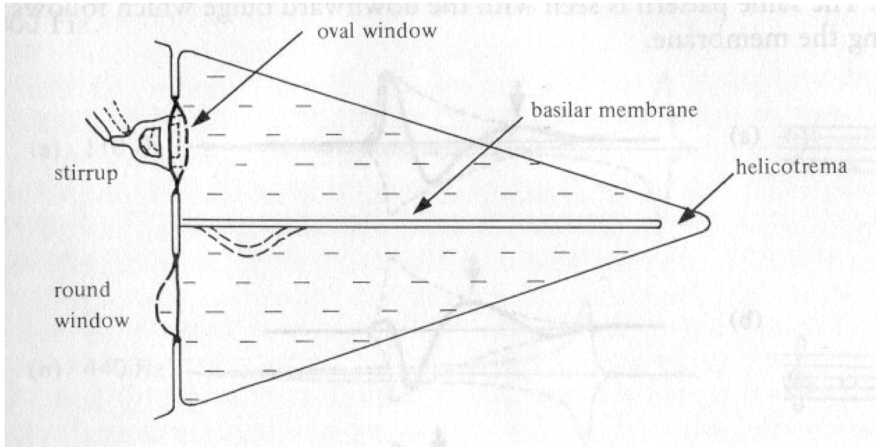


15. The peripheral auditory system

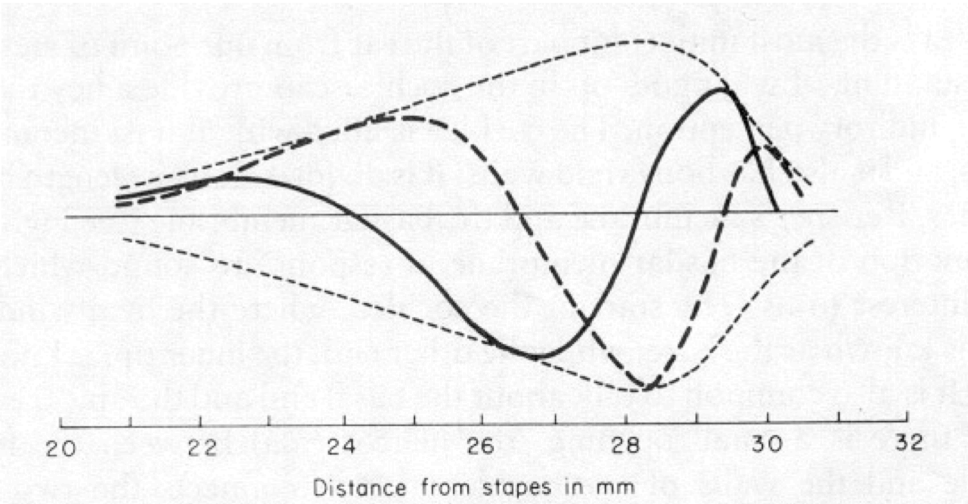


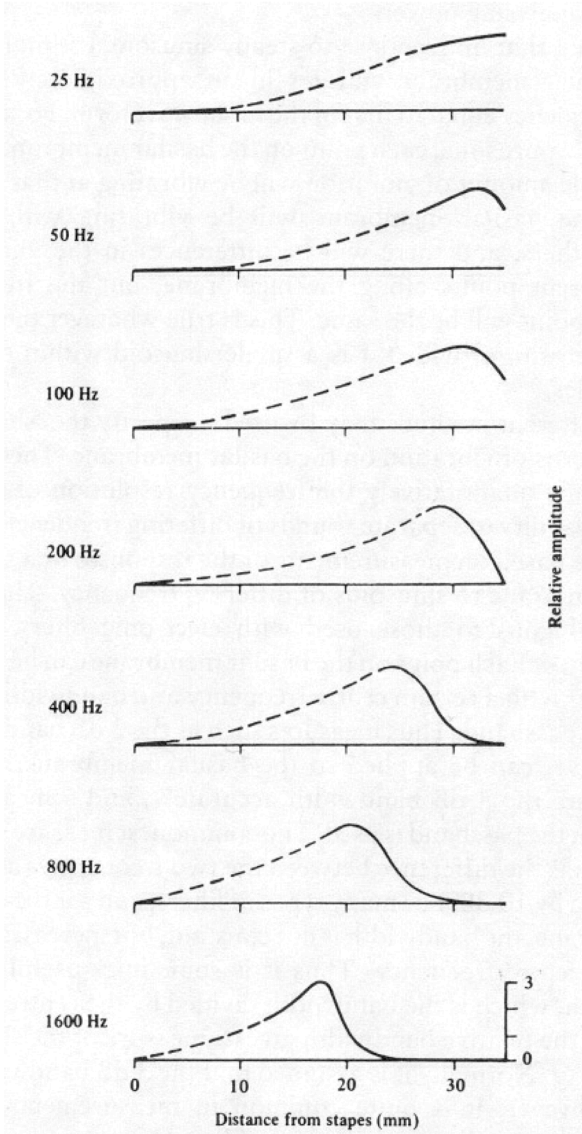
16. The inner ear



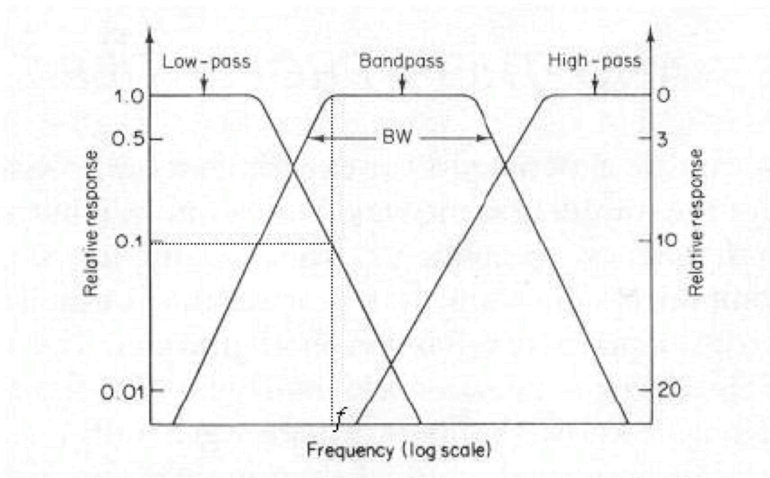


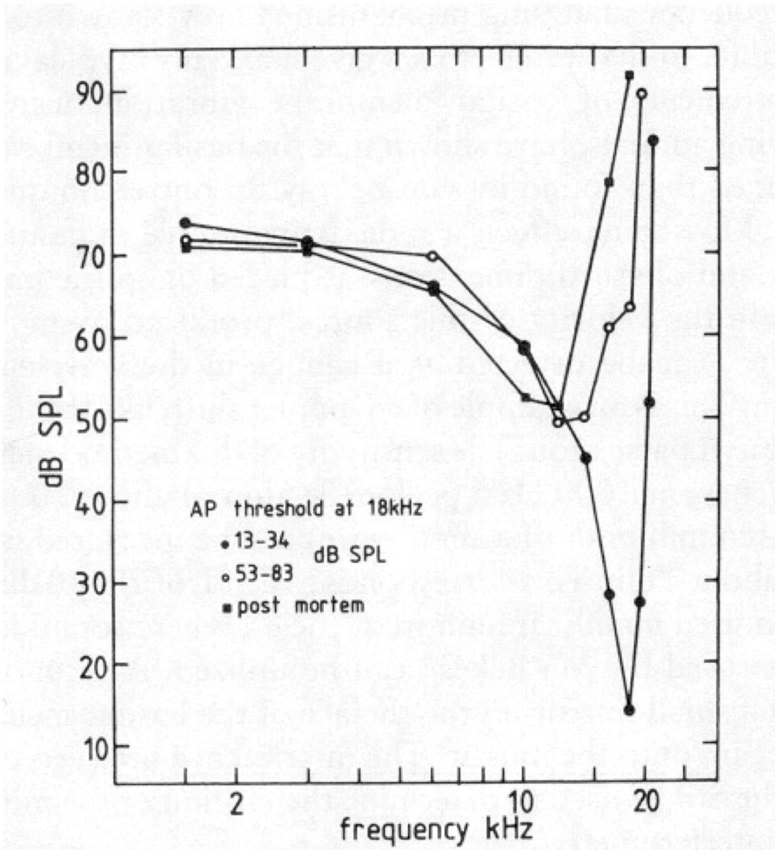
17. Patterns of vibration on the basilar membrane





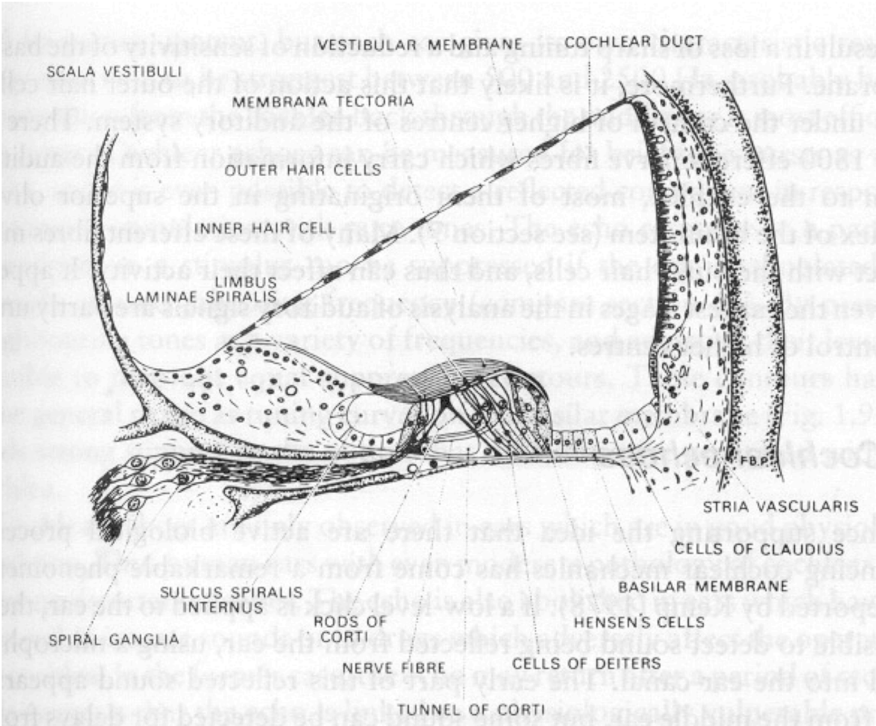
18. Frequency resolution of the basilar membrane

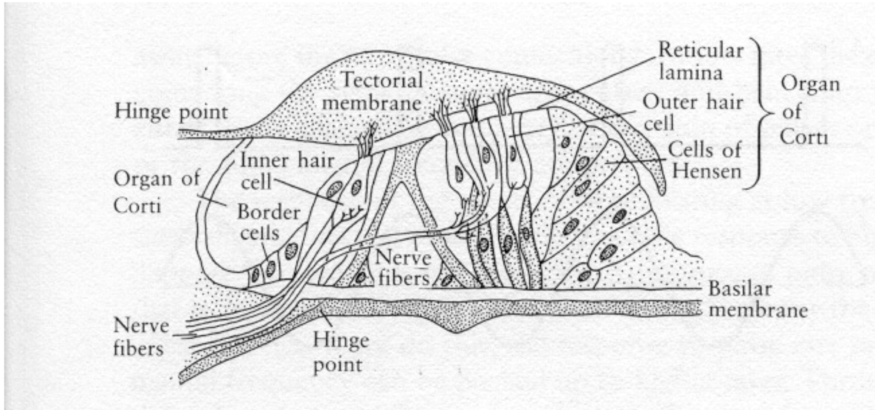




- *Relative bandwidth* of a bandpass filter is the ratio of the bandwidth to the centre frequency.
- Q is a measure of the sharpness of the tuning of a bandpass filter. It is the reciprocal of the relative bandwidth (i.e., ratio of centre frequency to bandwidth).

19. The transduction process and the hair cells





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